Fabrication of the Nanodimensional Elements by the Near-Field Optical Lithography Method

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Abstract

A method of contact scanning near-field optical lithoghaphy has been developed to enable fabrication of elements with characteristic dimensions of about 30 – 50 nanometres. The method involves deposition of a thin-layer polymer-metal coating, photothermal nonplastic deformation of top metal layer with a probe microscope, the transfer of the pattern through the polymer of dry etching and the formation of various nanoelements through this prepared mask. The method is applicable to any materials (metal, dielectric, light/heavy doped semiconductors) relevant to the formation of different nanometre objects (metal, dielectric, etched in surface or its combinations) on their surface.

1. Introduction

In the last few year much attention has been given to nanometre-object-devices including single-electron transistor, quantum dot/well systems etc. These devices are notable for a few unique features and capabilities such as charge carrier spectrum quantization, amplification and transformation of very weak signals, low dimensionality and extremely low energy consumption, which makes them the objects of choice for elements of electronic devices. The fabrication of these structure in the planar technology involves many difficulties related to such low dimensionality. Electron-beam and x-ray lithography today is only approaching the state where the fabrication of devices so small will become a reality.

Therefore, an alternative method, scanning probe lithography (SPL), that appeared as a trend of scanning probe microscopy, has aroused active interest [1-4] SPL provides an inexpensive, compact and convenient tool for nanometre size patterning of the sample surface and, in some applications, competes favorably with electron-beam and x-ray lithography.

Some attempts were made recently to use SPL in the development of integrated circuits. For example, in [5] this method was applied towards modification of a large-area surface (3 × 3 mm^2) with help grid 32 × 32 cantilevers (all 1024). A more attractive feature of SPL, however, in our opinion, is high-precision probe positioning (to 10 nm), which enables the imaging of a surface structure, selection of a desired area and activation of a probe at a specified point, all in one experiment. In this way it is possible to further develop locally a planar structure formed by an optical or electron-beam lithography technique or to make contact to individual nanoobjects on the sample surface.

In the SPL method, surface modification is effected by use of a microscope probe interacting with a small spot on the sample surface. There are a variety of SPL techniques. Convenient near-field optical lithography allows one to obtain pattern with a minimal size ~ 100 nm [6] because a small transmission coefficient power of optical radiation through probe at smaller aperture. The most interest results were achieved by the method involving a combination of a scanning tunneling/atomic force microscope. Here the probe is held over the surface by atomic force interaction, and surface modification is effected during the tunneling current flow through the probe-sample separation (anodic oxidation of the sample surface [2,3]). This method has been successfully used to produce pattern with a minimal size of 10 – 20 nm [2,7] and for development of a number of devices, such as a single-electron transistor operating at a room temperature[8] and field effect[9] and bipolar [10] transistor with ultrasmall dimensions of their active areas. However, this method can only be applied to a limited variety of samples with good conducting properties, the resulting pattern is only oxide layer which has a small aspect ratio and can generally be used further only for wet etching, being unable to serve as a mask for deposition purposes.

2. Experimental method and results

We have suggested and realized a new method of SPL which can be used to create a variety of nanometre elements (metal and dielectric dots and lines, dry-etched wells and grooves or its combinations) on the surface of different samples (lightly/heavily doped semiconductors, metals and dielectrics). The method involves deposition of a two-layer thin-film metal-polymer mask coating, photothermal nonplastic deformation of the top metal layer with a heated probe of a scanning near-field optical microscope (SNOM), followed by pattern transfer through polymer onto the sample surface, using a dry etching technique, and the formation of various nanoelements through this prepared mask.

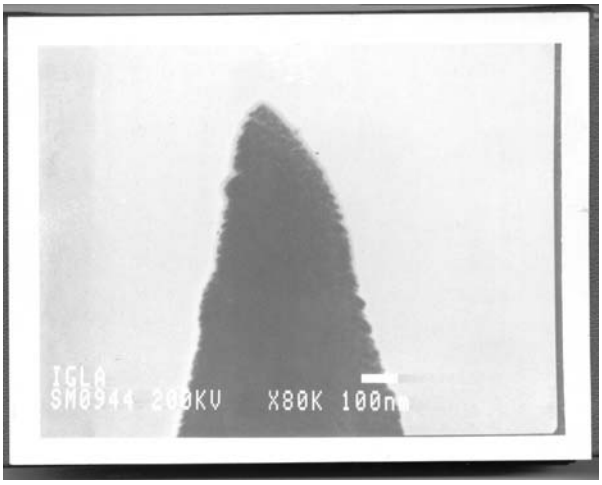
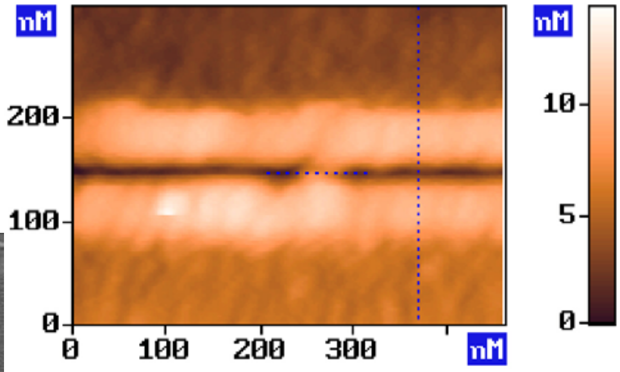
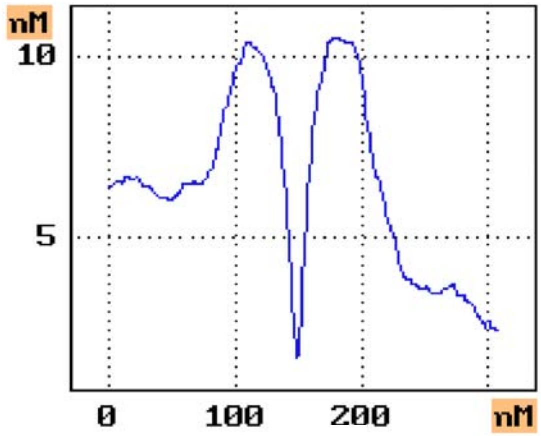


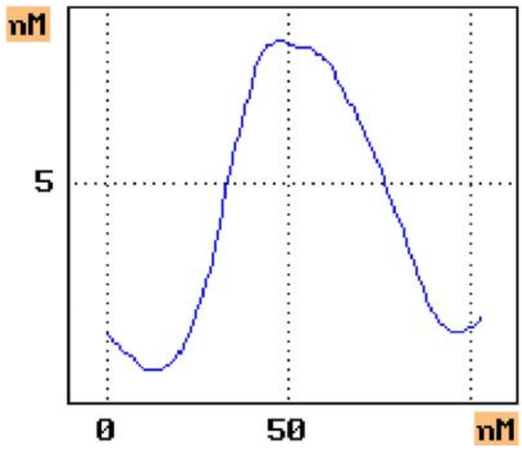
Fig. 1. Probe for surface modification on the base of optical fiber



a)



b)



c)

Fig. 2. Modified structure (a) and its cross section along vertical (b) and horizontal (c) axes

The software for creation of different nanoelements is developed. The advantage of this method is possibility of ruling by creating elements dimensions with help changing of probe temperature.

The mask coating applied to the sample surface is a thin layer of polycarbonate (50 – 100 nm) coated a very thin (5 – 10 nm) film of easy-to-deform and fusible metal – such as indium or tin. The mechanical and thermal properties of such a structure enable its nonplastic deformation to be carried out with a SNOM probes to a depth exceeding of a metal film. Experiments for photothermal modification of a mask coating surface were carried out on a SNOM "Solver P-4" (Nanotechnology MDT, Moscow, Russia). Earlier we had developed a method for NSOM probe fabrication, that involved only chemical etching [11]. In the experiments reported here we used a thinner version of the SNOM probe in which a tapered optical fiber tip was coated with just a 10 – 20 nm thick layer of vanadium (fig.1). The melting point for indium is 156^{0}C, which is lower than for polycarbonate; the SNOM probe can be heated up to T ~ 400^0C without being destroyed and therefore SNOM probe easy deform top metal layer. In our experiment the probe was heated to ~ 200^0C by nearly 300 μW optical radiation fed into it. Further, the structure was etched in oxygen plasma to enable pattern transfer through the polycarbonate layer onto the sample surface without changing the area that unaffected by the heated SNOM probe. The protecting mask thus formed may be used for deposition metal or dielectric films, dry etching the sample surface or its combinations with followed lift-off lithography. For example using this technique we fabricated the planar structure from two very narrow (≤ 30 nm) lines parted by short (≤ 50 nm) space interval etched in sample surface (fig. 2). Such a method for surface modification of polymer (without top metal layer) was used earlier towards superdense data recording [12] (rather than lithography).

It should be noted that all the above results are pioneering successful experiments in this area. It appears that, given thorough treatment and further development, this method may yield even better results.

3. Conclusion

In this report we have shown the possibility of fabricating planar elements with characteristic dimensions of about 30 – 50 nanometres by a contact SPL method. This technique can be used to create a variety of nanometre elements (metal, dielectric, dry-etched in sample surface or its combinations) on the surface of different samples (lightly/heavily doped semiconductors, metals and dielectrics). It offers a high positioning precision and can be used for modification of a planar structures fabricated by the optical or electron-beam lithography methods and to form contacts to a single nano-objects. The method can be applied to the development of nanoelectronic devices.

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